MODERN PHYSIOLOGY.

IF we define physiology in broad terms as the science of the phenomena of life, and characterise as its object the investigation of the phenomena of life, physiology is a very old science; as old, indeed, as human reflexion on any of the processes of nature. But the character of physiological thought has undergone in the course of the development of the human mind such manifold and profound changes that physiology has exhibited in different periods quite different aspects. So that for a critical judgment of the present state of the science a retrospect of certain phases of its past history, is very important.

THE EARLY VITALISM.

In the sixteenth century, after the long intellectual night of the Middle Ages, a sweet, refreshing zephyr proclaimed the dawn of a new era for all fields of human thought,—for art and philosophy, for science and medicine. Physiology did not lag behind in the new development. The exact method of natural inquiry, founded by men like Copernicus, Kepler, Galileo, Bacon, and Descartes, was, by Harvey's classical investigations on the circulation of the blood, also introduced into physiology, which at that time was still based on the old system of Galen. How greatly the rise of the exact critical method of inquiry promoted and stimulated the further development of physiology is best seen by the powerful growth of the two great schools of the seventeenth century, the *iatro mechanical* (iatro-physical, iatro-mathematical) and the *iatro-chemical*, the first of which, founded by the brilliant Borelli, sought to explain the phe-

nomena of life by the principles of physics, while the latter, founded by Sylvius, more especially employed the laws of chemistry for the explanation of the vital processes. Physiology was thus transformed into a physics and chemistry of the human body, an enormous number of physiological facts were disclosed, numerous theories were promulgated, and in the year 1757 Haller was able, on the basis of a stupendous mass of material, to give to the scientific world for the first time, in his "Elementa Physiologiae Corporis Humani," a large compendium of physiology.

But the hopes of the iatro-mechanical and iatro-chemical schools to explain all phenomena of life by the principles of physics and chemistry fell far short of realisation. Since the establishment and development by Glisson, Haller, John Brown, and others, of the doctrine of irritability, this latter property was recognised as a quite universal attribute of living organisms, as distinguished from inorganic bodies; physicians thought beyond a doubt that they saw in irritability the essence of life. But what was irritability? Here was something that did not admit of immediate physical or chemical explanation.

Perhaps it was lingering traces of the animism of Stahl, still fresh in the minds of scientists, or perhaps reminiscences of the mediæval notions of *πνεῦμα*, *δύναμις*, *spiritus*, and so forth, outgrowths of the doctrines of the ancient pneumatic physicians, that in the face of the difficulties of explaining mechanically the nature of the phenomena of life matured a doctrine which was subsequently to be of far-reaching consequence in physiology. Namely, the theory of *vitalism*.

The argument which forms the basis and gist of the theory of vitalism is as follows: since the processes of life do not admit of explanation by physical and chemical forces, there must be active in living organisms some other force which produces the phenomena of life, a force of a different kind from that which physics and chemistry take cognisance of, a vital force, *vis vitalis*, *Lebenskraft*, *force hypermécanique*.

The defect of this reasoning is manifest. All proof of the correctness of the minor premise is wanting. For, if hitherto and with methods which now exist, certain vital processes have not been re-

duced to physical and chemical causes, it follows by no means from this fact that *in a last analysis* they may not be conditioned by chemical and physical causes, or that *in the future* they will not be reduced to such. Vitalism, therefore, is simply a dogma of convenience.

Vitalistic ideas first appeared in the French schools of medicine, especially at Montpellier. In the track of the latter followed the German school of vitalism, whose founder was Reil. With most of the vitalists the vital force was thoroughly mystical, and never received a precise definition. In this fact its great convenience lay. Men spoke of a *nisus formativus* when they wished to explain why from the egg of a snake always a snake was developed, and from the egg of a bird always a bird. In some few exceptional cases though, by clear-headed thinkers, who would not rest satisfied with a hazy word, the idea actually was more precisely defined, but in such cases it almost always turned out that the essential principle of vitalism was sacrificed.

Johannes Müller, the greatest physiologist that the history of our science has produced, was a vitalist. He reckoned with a vital force. But in so clear a mind as Johannes Müller's, the idea of vital force could not preserve the slightest tinge of mysticism. To him, vital force was simply a peculiar, characteristic complex of the special factors which are realised in living bodies and form the basis of their expressions of life, but not an entity that worked in a manner opposed to chemical and physical laws. Subsequently, indeed, the term vital force was used in different senses, and even in Johannes Müller's time it no longer possessed a uniform significance, although it was then deeply rooted in physiological thought. Still, the unclear notion of a vital force was not definitively dispelled until the epoch of the great achievements of modern natural research, of comparative anatomy and of evolution, of the theory of descent and natural selection, of the investigations of chemical physiology, and above all, of the discovery of the law of the conservation of energy; and with the dissipation of this notion, the theory of vitalism was overcome.

THE PRESENT STATE OF PHYSIOLOGICAL RESEARCH.

Psychologically, it is a highly interesting phenomenon, and one of moment in the history of science, that now, almost immediately after the final suppression of the old vitalism by the new development of the natural sciences, we have again arrived at a point which corresponds in the minutest details to the reversion to mystical vitalism which took place after the clear and successful research of the preceding century. As a fact, the parallel between the conditions of the eighteenth century and those of to-day is unmistakable. Now, as then, the physico-chemical method of explaining phenomena of life looks back on a brilliant, almost dazzling sequence of successes; now, as then, the tracing of vital processes to physical and chemical laws has reached a point at which, for many years, with the methods now at our command, no essential progress has been made, where, on the paths hitherto trodden, a boundary line is everywhere distinctly marked; and now, as then, on the horizon of science the ghost of a vital force looms up. It has already taken possession of the minds of serious thinkers in Germany, with the dire prospect of more extensive conquests; and in France, too, it would seem, science is slowly opening its door to this invasion of genuine mysticism.

To understand this phenomenon psychologically, and to acquaint ourselves with the means of staving off a general reaction into vitalism, it is desirable to examine more carefully the present state of physiology. A review of the productions which appear in our different physiological journals, which will best exhibit the present state and tendency of the science, furnishes an extremely remarkable spectacle. Leaving aside the science of physiological chemistry, which is independently developing with great success, we find, with the exception of a few good contributions to the physiology of the central nervous system, as a rule, only extremely special performances of very limited scope and import, wholly without significance for the greater problems of physiology, whether practi-

cal or theoretical, and exhibiting no connexion whatever with any well-defined general problem of physiology. In fact, what is called physiology is beginning here and there to degenerate into mere technical child's play. With every new number of our physiological magazines, the unprejudiced observer is gradually gaining the conviction that general problems of physiology no longer exist, but that inquirers, driven to desperation in the struggle for material, have no choice but to hunt up the old dry bones of science, on which they fall with the nervous rapacity of hungry dogs. And in the case of most of the productions, this impression is strengthened by the fact that the results, when once found, are wholly disproportionate to the tremendous expenditure of labor and time which it might be seen beforehand they would require. And yet all the time the great problems of physiology everywhere stare us in the face and seek solution. For, if we regard the problem of physiology as the investigation of the phenomena of life, we are certainly yet very far from the solution of even its most important and most general problems. We need not go to the extreme that Bunge does in his excellent text-book of physiological chemistry, of maintaining that the phenomena of our organism which we have explained mechanically are not genuine vital processes at all, no more than is "the motion of the leaves and branches of a tree shaken by a storm, or the motion of the pollen which the wind wafts from the male to the female poplar." But it is certainly no exaggeration to say that what the splendidly-conceived methods of the great masters of physiology since Johannes Müller have explained, are not elementary processes of life, but almost exclusively the crude physical and chemical actions of the human body.

For what have we attained? We have measured and registered the motions of respiration, the mechanics of the gaseous exchange in the lungs in their minutest details. We know the motions of the heart, the circulation of the blood in the vascular system, nay, even the slightest variations of the pressure of the blood, as produced by the most diverse causes, as accurately as we do the phenomena of hydrodynamics in physics. We know that respiration and the motion of the heart are conditioned by the automatic activity of ner-

vous centres in the brain. But no spirometer, no kymograph, no measuring or registering apparatus can give us the slightest idea of what takes place in the nerve-cells of the brain that condition the beating of the heart and respiration.

Further, we have investigated the motions of the muscles, their dependence on the most diverse factors, their mechanical powers, their production of heat and electricity, as exhaustively as only the phenomena of the special departments of mechanical physics have hitherto been treated. But of what goes forward in the minute muscle-cells during simple muscular contraction, no myograph, no galvanometer has as yet given us the slightest hint.

We know also the laws of the excitability of the nervous fibres, of the propagation of irritations, of the direction and velocity of nervous transmission, thanks to the ingenious methods of recent physiology, in all their details. But of what is enacted during these processes in the nerve-fibres and in the ganglion-cell from which it ramifies, no induction-apparatus or multiplicator can give us the least information.

We know besides, that the heat and electricity produced by the body, and the mechanical energy of muscular work, are the consequence of the transformation of the chemical energy which we have taken into our bodies with our food. But by means of what chemical processes the cells of the individual structures take part in these achievements, the most sensitive thermometer or calorimeter will not disclose, and no thermal pile or graphical apparatus will indicate.

We might give any number of examples of this kind but those adduced exhibit distinctly enough the point to be signalised. What we have hitherto attained is this: we have measured, weighed, described, and registered the gross mechanical actions of the human body, for the most part with a degree of precision that would excite the astonishment of the uninitiated; we have also acquired a considerable knowledge of the rough mechanical interactions of the individual organs of the body, the mode of operation, so to speak, of the machinery of organisms. But all that has been done, has been done only up to a certain point; and this point, at which we are

brought to a halt, is the *cell.* We have traced all phenomena of change in matter, form, and force back to the point where they disappear in the cell. But of what takes place in the muscle cell, the ganglion-cell, the lymph-cell, the gland-cell, the egg-cell, the sense-cell, and so forth, we have not the slightest conception. Moreover, we discover here, that even the minutest cell exhibits all the elementary phenomena of life; that it breathes and takes nourishment; that it grows and propagates itself; that it moves and reacts against stimuli. The *elementary* riddles of life, accordingly, have so far defied all research.

A balance thus cast of the results of past physiological research does not, it must be admitted, exhibit a very encouraging outlook.

But the resignation of physiology has been strengthened by another prominent factor. This is the attitude of physiological research to psychical phenomena. This attitude is at the present moment a varying one. On the one hand, we still find secretly cherished the vain hope of a chemical and physical explanation of psychical processes, that is to say, of a reduction of them to the motions of atoms, even though Du Bois-Reymond, in his famous address on "The Limits of Our Knowledge of Nature,"* characterised such an undertaking as utterly futile; while on the other hand we meet with an absolute resignation in the face of this question—an attitude which is simply a frank acceptation of the conclusion of Du Bois-Reymond's address. Owing to the authority of its author, the "Ignorabimus" of Du Bois-Reymond has influenced great numbers of inquirers and produced in physiology a real paralysis of research, so that the abandonment thus effected of the solution of the old problem of explaining psychical phenomena mechanically has caused physiology for the most part anxiously and reverently to avoid any intrusion whatever of psychological questions. On the one side, then, is the idle hope of solving a problem which despite its being as old as human thought itself, research has not yet even touched; and on the other, an absolute renunciation of any treatment of the problem whatsoever.

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* *Ueber die Grenzen des Naturerkennens. Reden. Erste Folge.* Leipsic. 1886.

THE NEW VITALISM.

Exactly as happened in the preceding century, we have again arrived, after a long period of the most successful conquests in science, at a point where a barrier is placed to the methods hitherto pursued, and at which research has for a long time stood still without overleaping it. Again, as in the preceding century, we have psychologically the same constellation, and already the first signs are beginning to show themselves of a tendency of science to seek a second time its salvation in a theory of vitalism. Already voices are multiplying which proclaim that the phenomena of life will never be fully explained, while a few decades ago the confidence of successfully investigating all vital processes was without exception a universal one. As a fact, the same vitalistic ideas have already been promulgated by eminent natural inquirers, as were set forth by the vitalists of the early period.

The botanist Hanstein* has given unequivocal utterance to such ideas. Starting from the fact that the organs of animals and plants show a definite conformation according to the species from which they are descended, Hanstein arrives at the conclusion that there is inherent in living organisms some special formative power (*Eigengestaltungskraft*), which has nothing whatever to do with the forces of inorganic nature. "As long as it is a correct principle of science," says Hanstein, "that there must be different causes where there are different effects, it cannot be legitimately maintained that the formative processes of organisms which are seen constantly to strive towards some predetermined end are nothing but the combined effects of forces inherent in atoms and active as rays or vibrations." In this "special formative power" of Hanstein we recognise at once, and in unmodified form, the *nisus formativus* of the vitalists. True, Hanstein admits that physical and chemical forces, such as act in lifeless bodies, also come into play by way of supplement to

* Hanstein. *Das Protoplasma als Träger der pflanzlichen und thierischen Lebensverrichtungen.* Heidelberg. 1880.

the special formative forces of living organisms, but *specific* phenomena of life he refers exclusively to special formative powers. Also he sees the activity of these forces in the phenomena of the heliotropism of plants, of the geotropism of the roots and trunks of trees, of the chemotropism of zoöspores, and generally in all phenomena of irritation, while the same force is also discerned by him in what the zoölogy of earlier times called instinct. Indeed it is a remarkable sign that Hanstein at this late day conceives instinct as a *force* in the same sense as physical forces are conceived, that is, as the cause of motions. Yet Hanstein regards this assumption not only as necessary but also as highly useful. "It must be maintained in the face of all objections, that this hypothesis is for the time being the simplest; that if it does not exactly explain the majority of the observed phenomena of life it yet puts them under a monistic (!) point of view; that it is not in contradiction with other phenomena, and does not make out of a small miracle a greater one, but while it solves (!) many riddles, reduces most others to a single simpler one." These are the words of a serious naturalist at the end of the nineteenth century! The same views on this point, though not so clearly expressed, are also maintained by the well-known botanist Kerner von Marilaun and the pathologist Rindfleisch. Indeed, from many quarters a frank and unmistakable demand is made for the recognition of a "neo-vitalism."

Quite different from this pronounced reaction towards mysticism is the vitalism which the physiologist Bunge professes. Bunge is a man of sound philosophical and critical ability; and if he openly sets himself up for a vitalist he produces by so doing a false impression, for his vitalism, if closely examined, will be found to be something quite different from the vitalism of the old school.

True, Bunge openly takes his stand on the ground of vitalism, when he says,* "If you assert in refutation of vitalism that there are no other factors active in living beings save the forces and materials of unanimated nature alone, I must dispute your assertion."

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* *Lehrbuch der physiologischen und pathologischen Chemie.* Second Edition. Leipsic. 1889.

Yet we shall observe if we follow Bunge a little further that his vitalism is purely a subjective idealism, which has sprung from the perception that it is reversing the true order of things to attempt to explain psychical processes by a mechanics of atoms. Bunge says: "The essence of vitalism consists simply in taking the only right course of knowledge, that is, in starting from the known, or the inner world, in attempting to explain the unknown, or outer world." We see thus that Bunge is on the right path by his so-called vitalism for avoiding the *one* cause of reaction towards the old mysticism—namely, the impossibility of resolving psychical processes by the physics and chemistry of matter. But unfortunately at this point Bunge comes to a halt. Instead of drawing from this perception that the whole physical world consists simply of compounds of sensations or of percepts, as its ultimate and unavoidable consequence a demand for a monistic conception of the world, Bunge still lingers in the old dualistic notion of a contrariety between a living and a lifeless, a dead and an ensouled nature, to which he gives expression in the above-cited words, and sees no other way out of the difficulty at present than to go on resignedly working away in the old mechanical direction, which by his own confession is a reversion of the true method.

THE MONISTIC POINT OF VIEW.

They who have fought their way through to a monistic point of view will have little difficulty in finding a complete and satisfactory solution of this dilemma. If the world of bodies consists solely of compounds of sensations, then the whole world is a unitary existence, for the supposed and otherwise irreconcilable contrariety of a physical world and a psychical world is dissipated. When, therefore, we investigate the physical world in a scientific or physical manner, we really investigate, in so doing, the laws according to which our percepts or notions of the physical world arrange themselves and combine to form higher compounds, that is, we are really pursuing a psychological inquiry. All natural science consists of such work, and the so-called "mechanical" method of research which has hitherto universally obtained, and by its great successes proved it-

self so wonderfully productive, is not only fraught with no danger for him who is conscious that mechanism is not a thing which is opposed to and exists beyond the soul, but even finds its full justification. From a monistic point of view, therefore, the mechanical method of inquiry is not only, as Bunge believes, a provisional expediency, but actually an absolute necessity.

But in this case the mechanical method of inquiry must also be able to explain the phenomena of living as well as of lifeless bodies; in both cases we have to deal with bodies, and for both, the laws of those complexes of sensations which we call bodies must possess validity. But it is altogether a different undertaking to attempt to explain by phenomena of the physical world simple sensations, which unlike our conceptions of bodies are not complexes. An endeavor of this kind, such as the materialists are constantly but vainly undertaking, is like the absurd attempt to divide the series of whole numbers by a number which is not numerical unity. In the one case as in the other, of course, the computation cannot be performed.

The main obstacle that has stood in the way of the establishment of monistic conceptions is the supposed contrariety of body and soul, an idea familiar to human thought since the earliest times. In fact, it would seem at first blush a wonderful thing that this ancient idea of the ensoulment of physical things could have maintained itself with such tenacity till so late a day. If the physical world is in reality only conception, it seems at first almost absurd to think of a conception as being ensouled. Yet no one doubts for a moment that other human beings are ensouled, and only a few, that animals are ensouled. It is worth while to look more closely into this paradox. When we do so, it will be found that exactly in a monistic point of view is the corroboration, nay, the necessity, of this interesting phenomenon to be found. The idea of the ensoulment of physical objects or bodies is the first beginning of a psychological analysis of our conceptions of bodies. By thinking of a body as ensouled, man makes the first step in the analysis of his own conception of that body.

A little reflexion will at once make this clear. We need only look somewhat closely at our conception of our own body. The his-

tory of the development of the soul, as Wundt* and Preyer† have followed it in the history of the development of the mind of man and especially of the child, shows us in outline how our conception of our own individual body has arisen. The formation of this apparently compact ego is an inductive process. The first beginnings are made unconsciously, by primitive sensations being brought into mutual connexion. These are the original, as yet unconscious, individual egos of the different parts of the body, which subsequently we consciously distinguish. But, owing to the fact that these individual egos, in the course of a rather long development, are gradually referred to the egos of individual sense-organs, particularly to that of the sense of sight, as to something constant, the single, unified conception of a whole bodily ego is slowly developed, which, by the constant acquisition of new elements gradually reaches higher and higher stages of consciousness; for what we call consciousness is a fact of enormous comprehension and intricacy, which we can reverse, so to speak, and by the gradual elimination of single component parts, such as takes place, for example, in partial and total hypnosis, dreams, narcosis, and so forth, actually analyse into unconscious sensations. While the conscious ego by the intussusception of new elements is thus constantly widening, the notion of the ego is slowly formed which every normal man possesses, and which subsequently also he constantly extends. These are, of course, only the first beginnings of our investigations in psychogenesis, and many essential elements of our knowledge in this domain are still wanting. But these facts are now quite settled, that the formation of our notion of our own body is nothing more or less than the outgrowth and combination of certain simple sensations, images, thoughts, judgments, and so forth, which constantly increase in complexity and ultimately yield a product of extremest intricacy, namely, our notion of our bodily ego, so simple to superficial inspection.

Here, in any event, we have a first equation: What appears to

* Wundt, *Vorlesungen über Menschen- und Thierseele.* Leipsic, 1863.

† Preyer, *Die Seele des Kindes. Beobachtungen über die geistige Entwicklung in den ersten Lebensjahren.* Leipsic, 1881.

us as so compact and single an object as our body, is in reality an extremely complex synthesis of our own mind, the individual elements of which psychogenetic inquiry has only revealed with great difficulty, and that only to a very limited extent. But just as our notion of our own body is only a simple expression, a symbol, for an extremely complex psychical synthesis, such also are our notions of all other bodies, in the first instance of all other men, but then also of all animals and plants down to unicellular organisms, nay, even into the dark province of molecules and atoms which make up the lifeless bodies of nature. The formation of our notion of the world of bodies is nothing else than an extension of our own Psyche.

When, therefore, we picture to ourselves a body as ensouled in the same way that we conceive our own body ensouled, with these or those sensations or groups of sensations, in doing this we only analyse our apparently single and compact notion of the body, be it of a man or of an animal or what not, according to the standard of our present knowledge, into the simpler component elements out of which it has been psychogenetically constructed. Proceeding rigorously and logically from our first equation we obtain thus by conceiving bodies as ensouled a multitude of new equations, from many of which we can eliminate and isolate certain factors more easily and distinctly than from the first. But we have no right, if we are determined to be logical and consistent, to stop with the conception of ensoulment at man, as early times did, or at animals, as is now usually done, or, for that matter, at organisms at all: it is an inexorable consequence which, foreshadowed by ancient philosophers, has been more distinctly expressed in modern philosophy, and in natural science especially set forth and expounded with great lucidity by Haeckel, that *all* bodies must be regarded as ensouled, though ensouled it may be in different ways.

Thus from the monistic point of view the apparent dualism of the world of body and the world of soul finds its just appreciation. Monism alone disposes in a simple and satisfactory manner of the old, old problem of the relations of the body to the soul, of the material to the spiritual world,—a problem whose insolubility from the point of view of dualism again threatens to drive us into the arms

of vitalism. While at the same time monism also tears down the last barrier which Bunge is disposed to see between living and lifeless nature—namely, ensoulment.

CELLULAR PHYSIOLOGY.

If on the one hand we can justly cherish the hope that the increasing extension of the monistic world-view in natural science will ward off the dangers of a reaction to the old vitalism, the fact nevertheless remains that in treading the beaten paths we are making no progress whatever in physiology, and that we have stood still for years on the same spot and not approached a single step nearer our goal of explaining the elementary phenomena of life.

We have reached a turning-point in physiological research which could scarcely be made more prominent. The reappearance of vital force is a token of it. As before all great crises of history portentous spirits appear to clairvoyant people, so in our days the ghost of the old vital force has loomed up in the minds of some of our natural inquirers.

But striking and obvious as the fact is that we can no longer approach by the old paths of research an explanation of the elementary phenomena of life, still, it is exactly as obvious and striking in what direction there is the only chance or hope of our approaching our goal.

We have traced the vital processes of man in physiology back to the point where they are lost in the cell. Now, what is more reasonable than that we should seek them out in the cell? In the muscle-cell is hidden the riddle of muscle-movement, in the lymph-cell is hidden the causes of secretion, in the epithelial cell is buried the problem of resorption, and so on. The theory of the cell has long since disclosed that the cell is the elementary foundation-stone of the living body, the "elementary organism" itself, that in which the processes of life have their seat; anatomy and evolution, zoölogy and botany, have long since realised the significance of this fact, and the wonderful development of these sciences has furnished a brilliant proof of the fruitfulness of this branch of inquiry. Only in physiology was the simple, obvious, and logical consequence over-

looked, and until very recently not practically applied, that if physiology regards it at all as her task to inquire into the phenomena of life, she must seek these phenomena at the spot where they have their origin, at the focus of life-processes, in the *cell.* If physiology, therefore, is not simply content with confirming the knowledge which is already gained of the crude mechanical actions of the human body, but makes it its object to explain clearly elementary and general phenomena of life, it can accomplish this object only as cellular physiology.

It may appear paradoxical, that although nearly half a century has elapsed since Rudolf Virchow first enunciated in several classical works the cellular principle as the basis of all organic inquiry, a basis on which to-day, indeed, all our ideas in pathology are constructed, physiology still is only just beginning to develop out of a physiology of organs into a physiology of cells. Yet this is the true and normal course of development of science which always advances from the crude to the delicate. And it would, therefore, be impardonable ingratitude and a mistaking of the mode of development of human knowledge if we should seek in the least to underrate the high importance of the physiological research of the past epoch, on whose shoulders in fact we stand, and with whose results we more or less consciously continue our work. Further, in our judgment of the course of development of physiological research, a factor must not be overlooked which controls the development of every science, namely, the psychological factor of fashion. The development of every science depends on the stupendous influence of great discoveries. Wherever we cast our eye in the history of inquiry, we find that great discoveries such as, to take the case of physiology, are represented in the works of Ludwig, Claude Bernard, Du Bois-Reymond, and Liebig, deflect interest from other fields and induce a great multitude of inquirers to pursue research in the same direction with the same methods, especially when these methods have proved themselves so wonderfully fruitful as in the cases adduced. Thus, certain departments of inquiry become, in connexion with epoch-making performances, fashionable, and the interest of thinkers in others subsides. But an equalisation in the course of time is always

re-effected, for every field of inquiry, every method of inquiry is finite and exhausts itself in time. We have now reached just such a point in physiology: the physiology of organs is in its period of exhaustion. Also the method of cellular physiology will exhaust itself in the course of time, and its place will be taken by other methods which the present state of the problem do not yet require.

But for the present the future belongs to cellular physiology. There are, it is true, inquirers who, although they are convinced of the present necessity of a cellular physiology, and see perfectly well that the cell as the focus of the processes of life must now constitute the real object of research, yet doubt for technical reasons whether it is possible to get at the riddles of life as they exist in the cell. It may, therefore, be justly demanded that some way, some methods be shown with which a cellular physiology can be founded. The doubt of the feasibility of this undertaking is in great part the outcome of a phenomenon, which, unfortunately we must say, has characterised physiology ever since the death of Johannes Müller, namely, the total lack of a comparative physiology. Physiology has not yet entered on this rich inheritance of the great master. How many among the physiologists of the day are acquainted with other objects of experiment than the dog, the rabbit, the guinea-pig, the frog, and a few other higher animals! To how many are the numerous and beautiful objects of experiment known which the wonderful luxuriance of the lower animal world offers! And yet just among these objects are to be found the forms which are best adapted to a cellular-physiological solution of physiological problems.

Naturally, if we believe we are limited, in our cellular-physiological treatment of the riddles of motion, digestion, and resorption, solely to man and the higher animals, we shall encounter in our investigation of the living muscle-cell, lymph-cell, epithelial cell, and so forth, more or less insuperable technical difficulties. And yet the splendid researches of Heidenhain on secretion, digestion, lymph-formation, and so forth, have shown what good results the cellular-physiological method can achieve even here. Well-planned histological experiments, such as those which put the liv-

ing cell in its intact connexion with the remaining woof of the body under given conditions, and then investigate the results in the suddenly slaughtered animal, to get from such experiments light on the processes peculiar to the condition of life, undoubtedly furnish the germ of much valuable knowledge. But it is of the very nature of these experiments that they must always remain difficult and restricted, for the *living* object, the tissue-cell, is accessible to microscopic investigation only with the greatest difficulty. Comparatively small difficulties in this respect are offered only by the free-living cells of the organism, as, for example, by the leucocytes or blood-corpuscles. And as a fact, by the researches of Metschnikoff, Massart, Buchner, Gabritchevsky, and many others, we have recently acquired some important and wide-reaching experimental knowledge concerning the vital phenomena of these very objects.

But if we place ourselves at the point of view of comparative physiology which Johannes Müller represented throughout his whole life with such success and energy, an infinitely broad perspective opens itself up for cellular investigations. A comparative view shows one fact of fundamental importance, namely, that elementary life-phenomena are inherent in every cell, whether it be a cell from the tissues of higher animals or from the tissues of lower animals, whether it be a cell of a plant, or, lastly, a free cell, an independent unicellular organism. Every one of these cells shows the general phenomena of life, as they lie at the basis of all life, in their individual form. With this knowledge, all that it is necessary for the inquirer to do is to select for every special object of experiment the fittest objects from the wealth of forms presented, and with a little knowledge of the animal and plant world, such forms really obtrude themselves on the attention of the experimenter. Accordingly, it is no longer necessary to cleave so timorously to the tissue-cells of the higher vertebrate animals, which, while alive and in normal environment, we can only use for microscopic experiments in the rarest and most exceptional cases; which further, the moment they are isolated from their tissues, are no longer in normal conditions and quickly die or give reactions that may easily lead to wrong conclusions and to errors. Much more favorable are the tissue-cells of

many invertebrate, cold-blooded animals or plants which can be more easily investigated in approximately normal conditions of life; yet even these, as a rule, will not outlast protracted experiments. But here appear as the fittest imaginable objects, for cellular-physiological purposes, free-living unicellular organisms—namely, protists. They seem to be created by nature expressly for the physiologist, for they possess, besides great powers of resistance, the incalculable advantage of existing in a limitless variety of form, and of exhibiting, as the lowest organisms that exist, all phenomena of life in their simplest conditions, such as are not to be found among cells which are united to form tissues, on account of their one-sided adaptation to the common life of the cellular colony.

Concerning the application of experimental physiological methods to the cell, we need be in no perplexity as to which we shall choose. In the luxuriant multiplicity of form which this world presents, there can always be found for every purpose a great number of suitable objects to which the most different special methods can be capitally applied.

We can, to begin with the simplest method, apply in the easiest manner imaginable to the free-living cell the method of simple microscopic observation of vital processes. In this manner mere observation has furnished us knowledge of the individual life-phenomena of cells in many details and also of their mutual connexion. Among the most recent achievements of this simple method may be mentioned only the extremely valuable knowledge concerning the more delicate and extremely minute circumstances of fecundation and propagation which Flemming, Van Beneden, the Hertwigs, Strasburger, Boveri, and many others have gained in recent years, partly from living cells and partly from cells fixed in definite conditions of life.

Moreover, we can also conduct under the microscope vivisectional operations on unicellular organisms in exactly the same scope and with greater methodical precision than can be done on the higher animals. Several inquirers, as Gruber, Balbiani, and Hofer, have already trodden this path with great success, and a considerable group of researches has shown distinctly enough the fruitful-

ness which this cellular vivisectional method of operation promises for the treatment of general physiological problems. With this vivisectional method also Roux, the Hertwigs, and others conducted their splendid investigations on the "mechanics of animal evolution," by showing what functions in the development of animals fall to the lot of the different parts of the egg-cell or to the first filial cells that proceed from their division.

We can also apply here, in its whole extent, that powerful physiological method known as the method of irritation, and investigate the effects of different kinds of irritation on the life-phenomena of the cell or of different cell-forms. The vegetable physiologists have already collected a great mass of material in this field. But also in the department of animal physiology a great number of recent works have endeavored to prove that the phenomenon of irritation which takes place on the application of chemical, mechanical, thermal, galvanic, and luminous stimuli to unicellular organisms are of the greatest importance for the phenomena of life generally.

Finally, we can approach the life-phenomena of the cell chemically, although in this direction only the very first beginnings have been made, seeing that the microchemical methods have been hitherto little developed. Nevertheless, the labors of Miescher, Kossel, Altmann, Zacharias, Löwitt, and others have already shown that the microchemical investigation of the cell has a future of great promise.

In the meantime, it is a gratuitous task to enumerate the individual methods that are capable of application in the domain of physiology. All methods may be used which the special experimental object of the moment requires.

Ever and anon in physiology must we revert to the point of view which formerly so fruitfully shaped the research of our great master, Johannes Müller. Johannes Müller, during his whole life, practically and theoretically represented the view that there is no one physiological method, but that every method is admissible which leads to the goal. He always chose his method to fit his problem and never, as is now so often done, the problem to fit his method. Not the method, but the *problem* of physiology is single

and unique. In the solution of this problem physiology employs chemical and physical, anatomical and developmental, zoölogical and botanical, mathematical and philosophical methods of inquiry, according to what the special object in view requires. But all methods shall lead to one goal only, the solution of the question, What is Life?

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